FINNISH METEOROLOGICAL INSTITUTE

FTIR methane profile retrieval using dimension reduction method

S. Tukiainen[1], J. Railo[2], M. Laine[1], J. Hakkarainen[1], R. Kivi[1], P. Heikkinen[1], H. Chen[3,4] and J. Tamminen[1]

[1]Finnish Meteorological Institute, Finland
[2]University of Jyväskylä, Finland
[3]University of Groeningen, the Netherlands
[4]University of Colorado, USA

Motivation

- Develop alternative retrieval algorithm for remote sensing of greenhouse gases that would allow studying non-linearities in the retrieval - **GOSAT RA project.**

- We aim to improve Sodankylä Fourier Transform Spectrometer methane retrieval by using Dimension Reduction method, in particular, observations in polar vortex conditions.

- Bayesian framework for detailed characterization of the posterior distribution and the uncertainties are obtained by applying Markov chain Monte Carlo (MCMC) technique.

FINNISH METEOROLOGICAL INSTITUTE

Sodankylä FTS

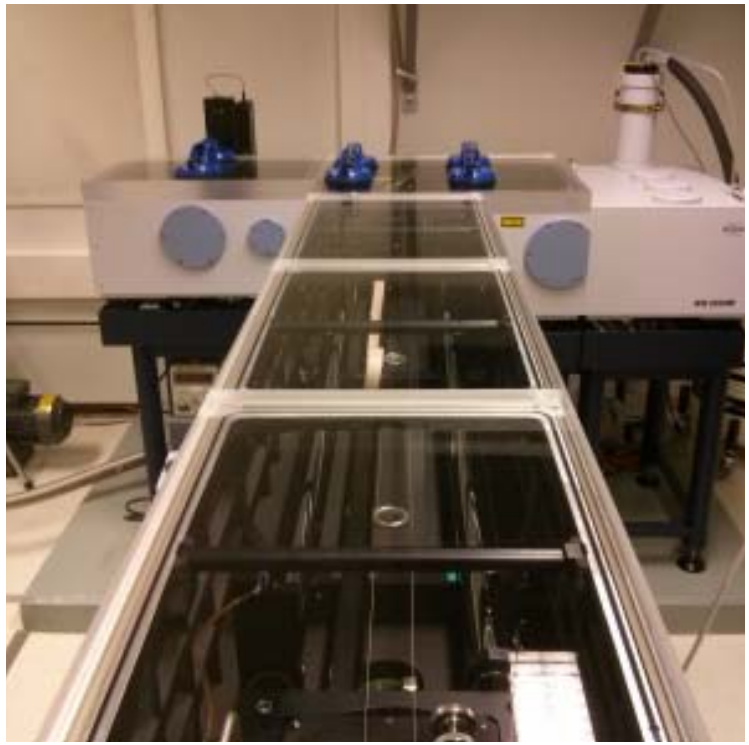
67.3668N, 26.6310E

Bruker *IFS 125HR* with *A547N* solar tracker.

Detectors:

RT-InGaAs:	*12800 - 4000 cm^{-1}*
RT-Si:	*25000 - 9000 cm^{-1}*
LN-InSb:	*10000 - 1850 cm^{-1}*

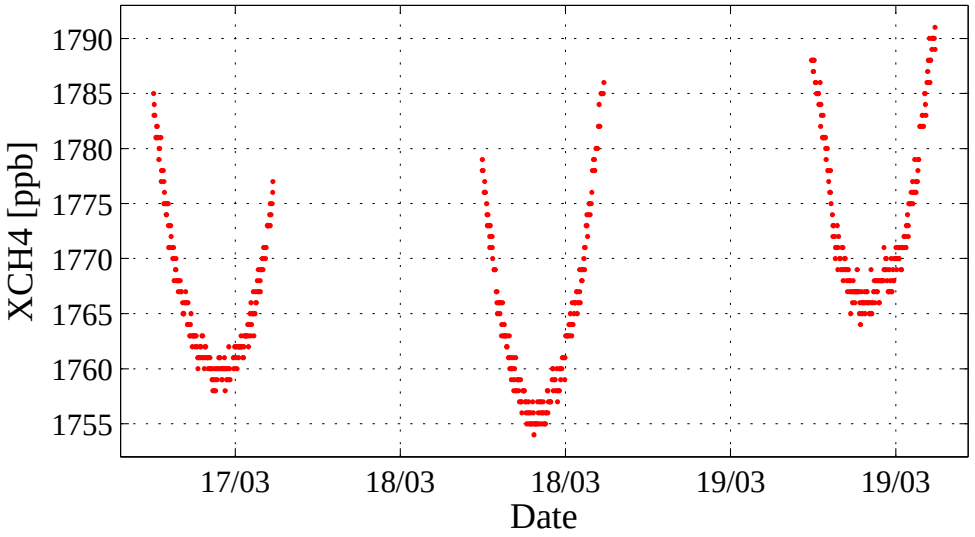
- In operation since February 2009
- Part of TCCON network
- Used extensively for GOSAT methane and carbon dioxide validation at high latitudes
- Target site for OCO-2 validation



FINNISH METEOROLOGICAL INSTITUTE

FTIR retrievals at high latitudes

- Standard FTIR retrieval algorithm is based on scaling climatological prior profile to obtain the best fit.
- In vortex conditions there can be large discrepancy between the true and the prior profile



- Large solar zenith angle dependency in XCH_4 during polar vortex when the prior is far from the truth.
- The U-shape largely explained by the averaging kernels
- However, varying averaging kernels are problematic when interpreting the data.

CH_4 profile retrieval using dimension reduction

- FTIR measurements contain some profile information but to retrieve a full profile (100 layers between 0-70 km) is a strongly ill posed problem.
- We reduce the effective dimension of the unknown methane profile using a low dimensional representation of the prior covariance.

- Prior: $\boldsymbol{x} \sim \mathcal{N}(\boldsymbol{x}_0, \boldsymbol{C})$

- Low rank approximation of the prior covariance using SVD

$$\widetilde{\boldsymbol{C}} = \sum_{i=1}^{k} \lambda_i \boldsymbol{u}_i \boldsymbol{u}_i^T = \boldsymbol{P}_k \boldsymbol{P}_k^T,$$

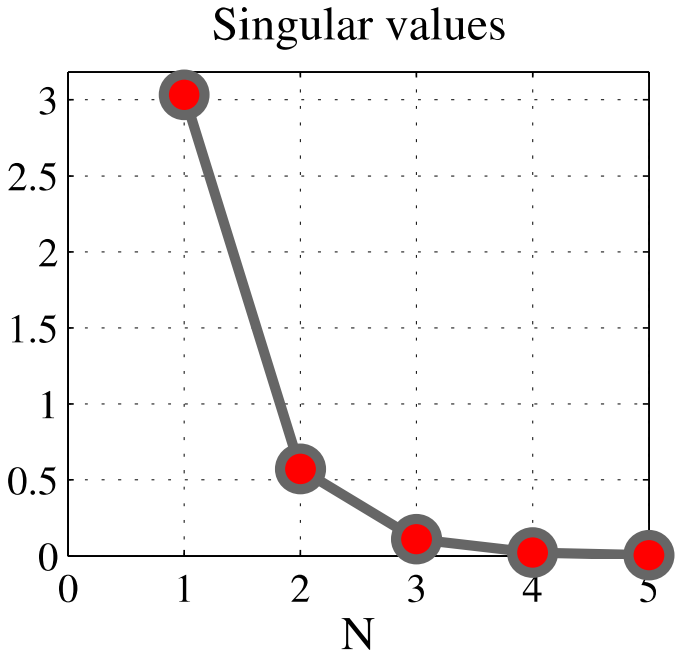
- Computationally easy to solve the low dimensional representation:

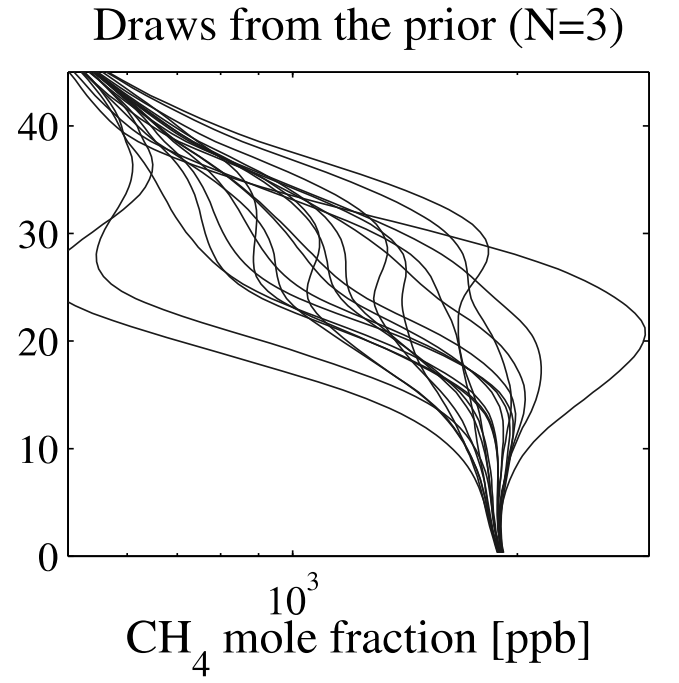
$$\boldsymbol{x} = \boldsymbol{x}_0 + \boldsymbol{P}_k \boldsymbol{\alpha}_k, \qquad \boldsymbol{\alpha}_k \sim \mathcal{N}(0, \boldsymbol{I}_k)$$

FINNISH METEOROLOGICAL INSTITUTE

Dimension reduction prior

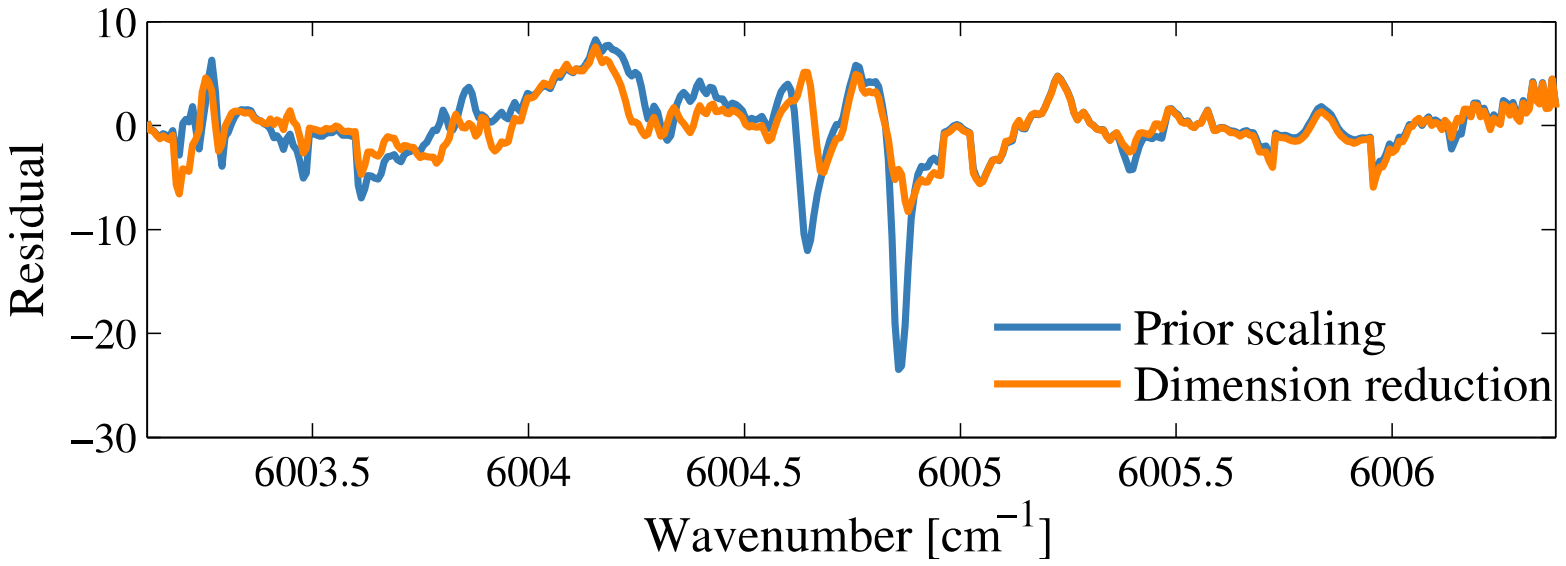
- Covariance for the original prior is developed using ACE-FTS observations and information on FTIR instrument sensitivity.
- Large variability allowed at UTLS, some variability below 10 km and very little above 35 km.
- Main characteristics obtained using three largest singular vectors.
- Draws from the prior show smooth profiles

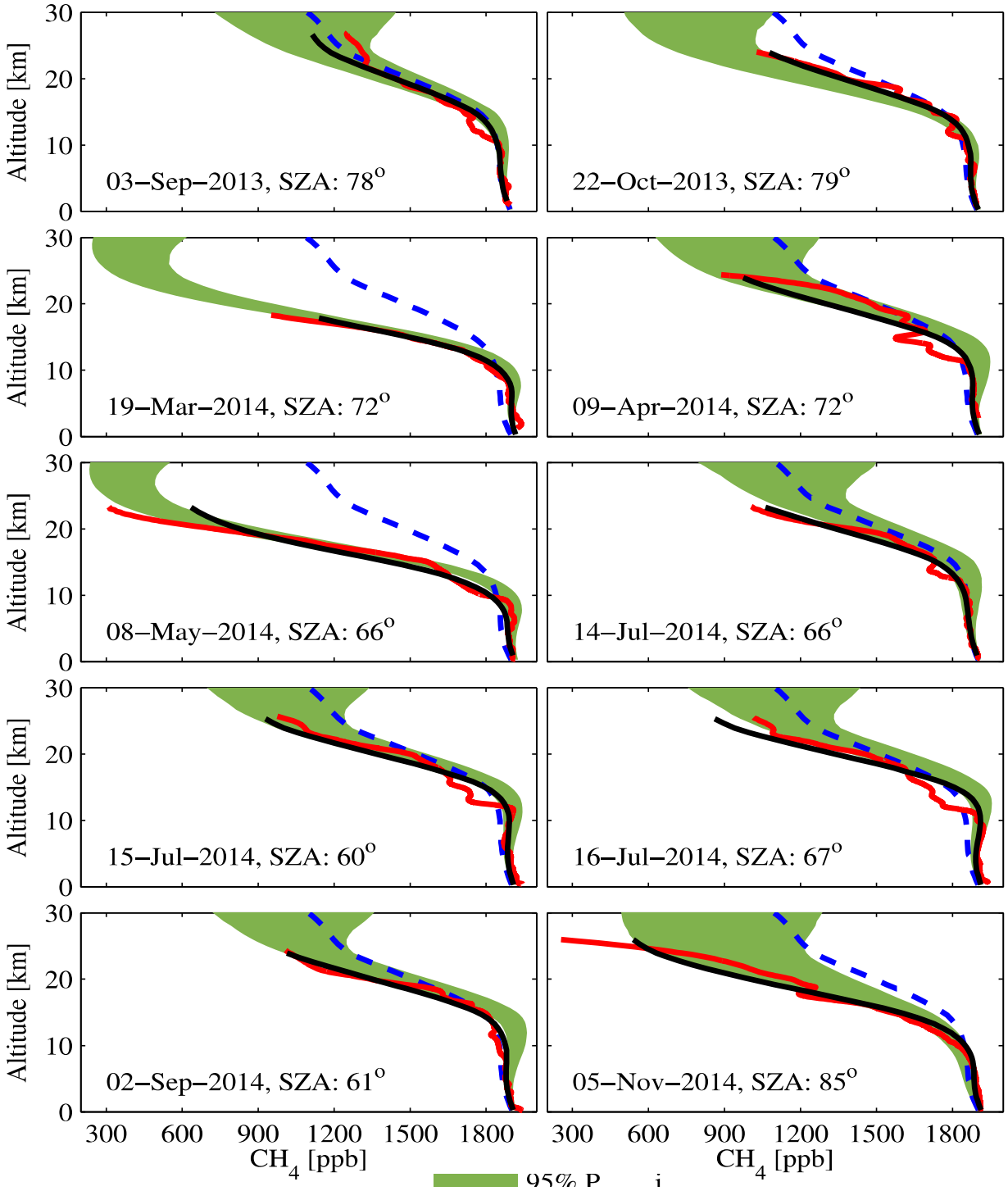




Improvement in the residual

- Overall fit is better.
- Largest residual peaks are removed





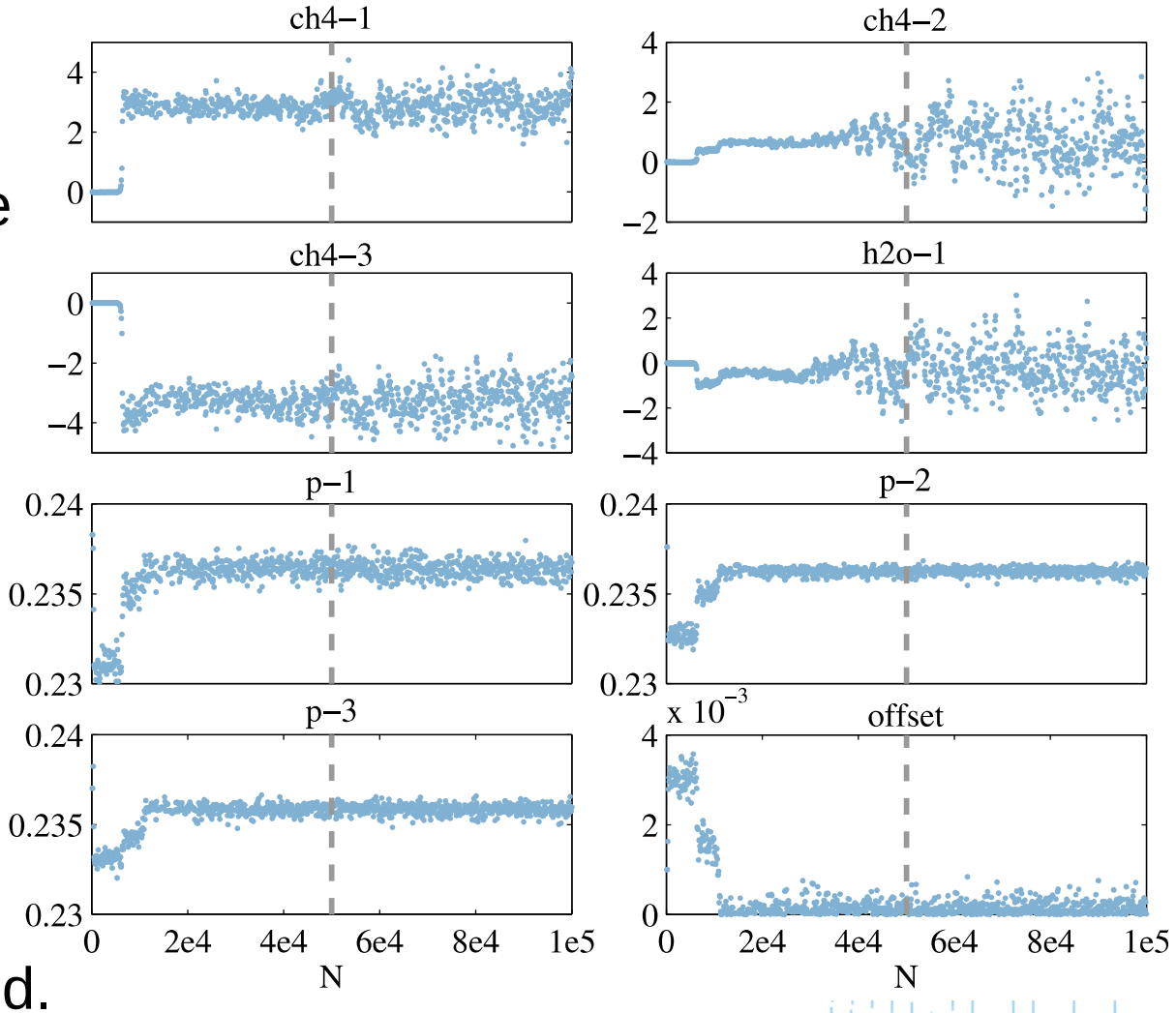
95% Posterior
Prior mean
AirCore
AirCore (smoothed)

Tukiainen et al, 2016, submitted to JGR.

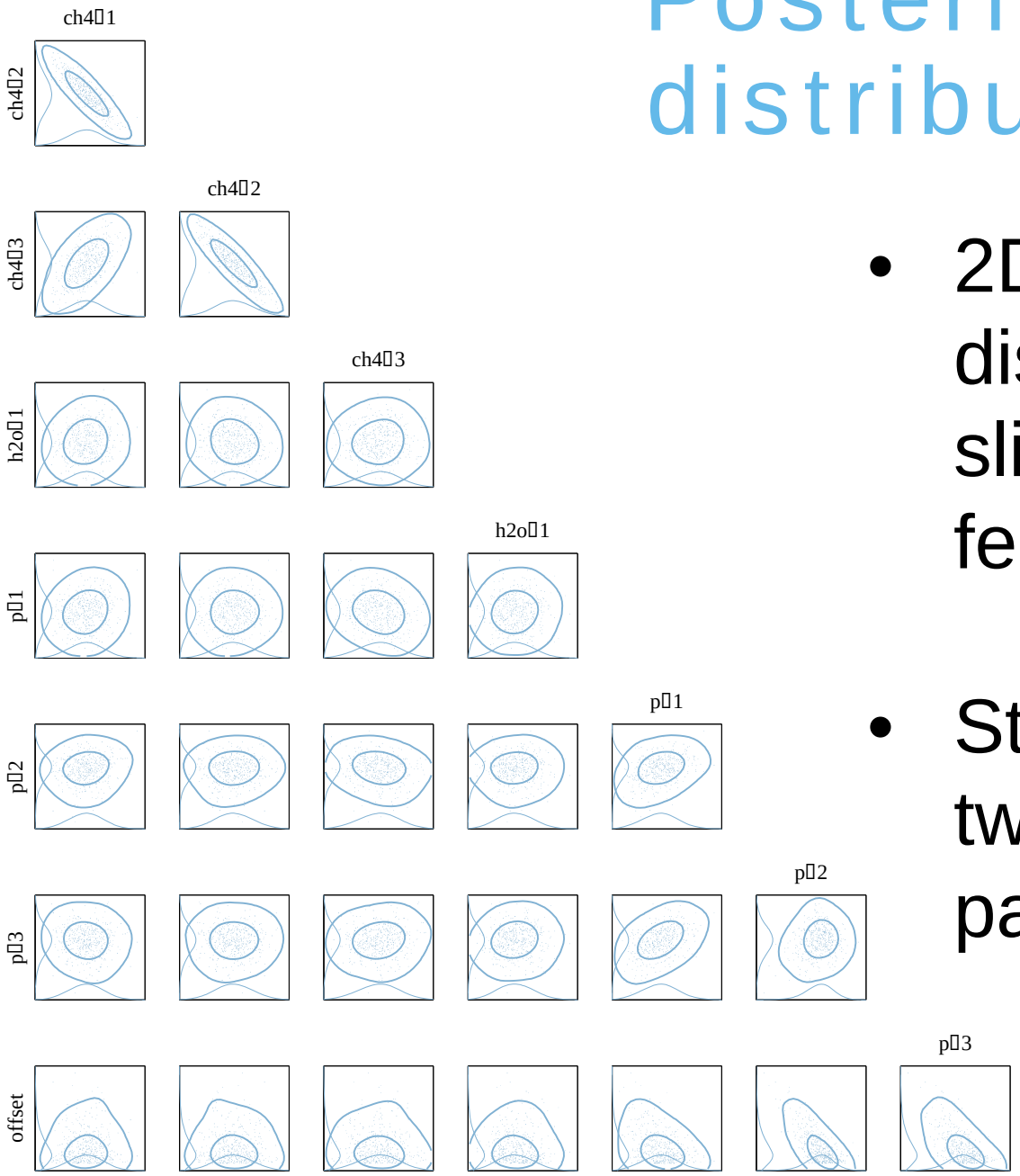
FINNISH METEOROLOGICAL INSTITUTE

MCMC samples of the posterior distribution

- Dimension reduction allows computation of the full posterior distribution using Markov chain Monte Carlo technique
- 100 000 samples from the posterior distribution computed
- Adaptive MCMC by Haario et.al. 2004 and Haario et. al. 2006 applied.

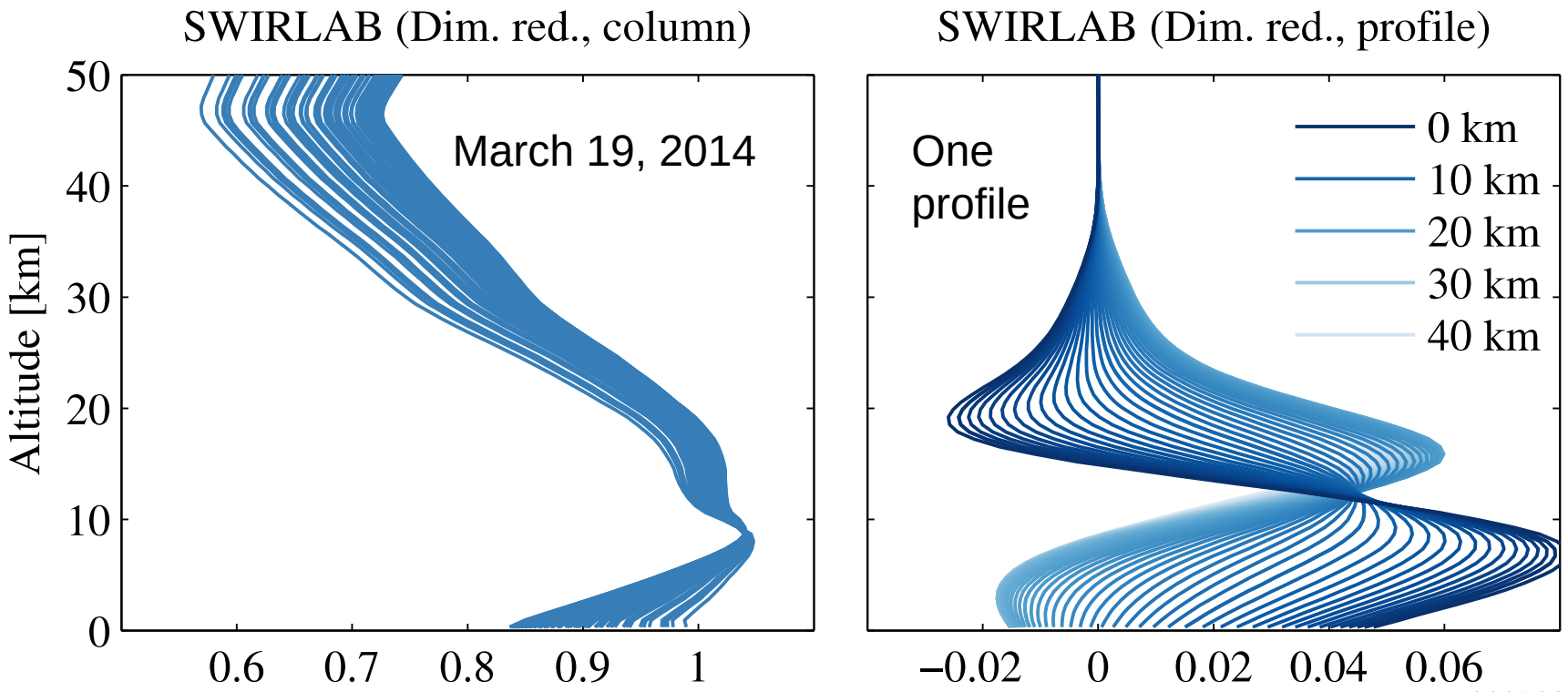


Posterior distribution



- 2D pairwise marginal distributions show slight non-Gaussian features
- Strong correlation in two methane parameters

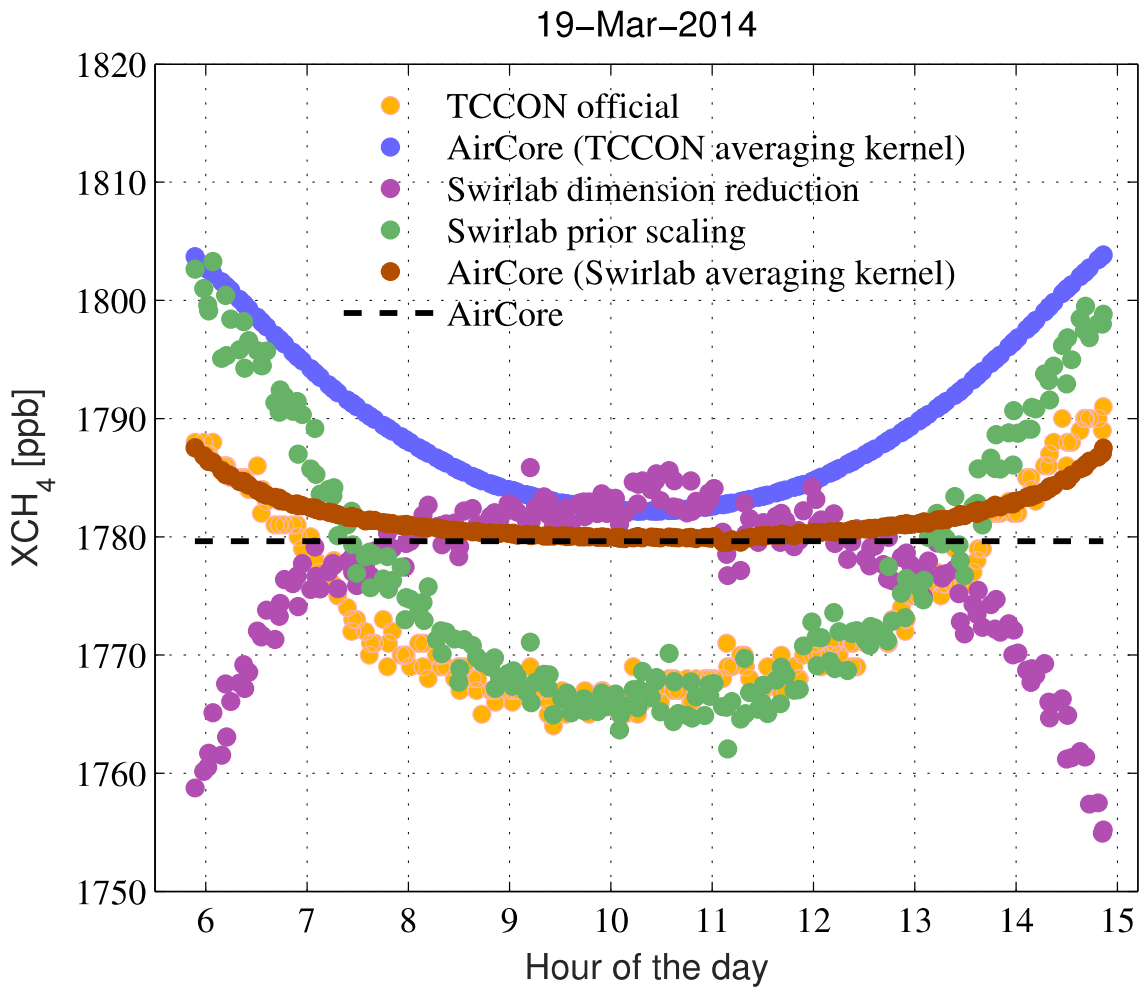
Averaging kernels



Summary and discussion

- Dimension reduction technique is developed for retrieving methane profiles from FTIR observations.
- The methodology is applied to Sodankylä FTIR observations.
- The retrieved profiles are in good agreement with AirCore profiles
- Low dimensional problem allows computing posterior distributions using the adaptive MCMC methods.
- The developed method is generic and can be applied to other gases and satellite data retrievals.
- **Tukiainen et al, submitted to JGR, 2016**

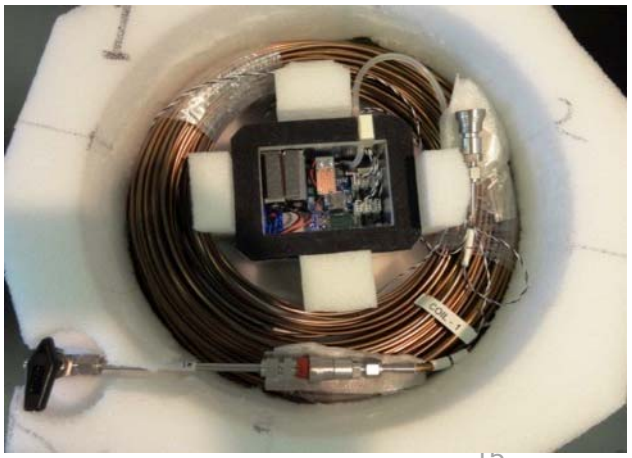
Comparison of daily observations with averaging kernels



AirCore profile observations at Sodankylä

- Started in fall 2013.
- Regular flights since then. Good flight conditions needed.
- Campaigns in summer 2014 and 2015

Chen et al, in preparation



AirCore instrument with an open cover